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AIRCREW PART-TASK TRAINING RESEARCH AND DEVELOPMENT IN THE 1980s: LESSONS LEARNED

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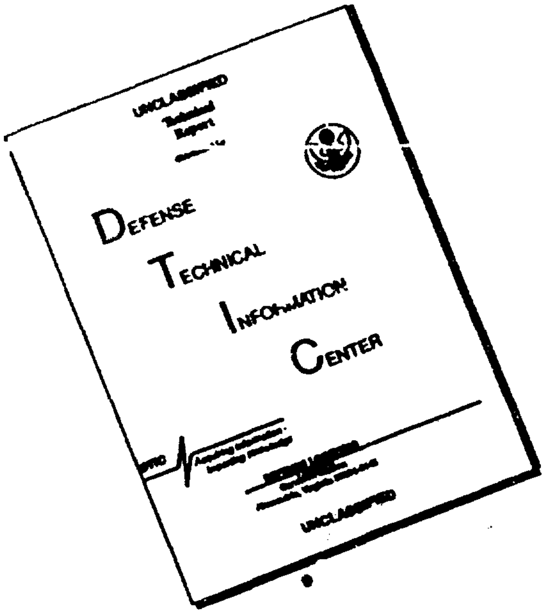

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The Public Affairs Office has reviewed this report, and it is releasable to the National Technical Information Service, where it will be available to the general public, including foreign nationals.

This report has been reviewed and is approved for publication.

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Throughout the 1980s the Aircrew Training Research Division of the Human Resources Directorate, Armstrong Laboratory sponsored various research and development (R&D) activities involving part-task training concepts. The R&D accomplished during this period was fueled by training device cost considerations, unit-level training needs, applications of new approaches in cognitive science, and the explosive development of the microprocessor In total, seven part-task training devices were developed by this division. This report describes these devices and the research performed using them. In addition, the "lessons learned" from research, as well as suggestions for future research in part-task training, are discussed.

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PREFACE

Part-task training has proved to be both practical and highly cost effective as a method of training Air Force aircrews. The present report is a descriptive summary of scientific and technical efforts to improve the technology of part-task training. The program described herein is a portion of the research and development activity of the Armstrong Laboratory's Human Resources Directorate, the thrust of which is Aircrew Training Development. The general objective of this thrust is to identify and demonstrate cost-effective methods and media in training Air Force aircrew members. The program was conducted primarily under Work Unit 1123-25-03, Special Function Trainer Prototypes. The principal investigators were Dr. Bernell J. Edwards and Mr. Garry H. Boyle.

AIRCREW PART-TASK TRAINING RESEARCH AND DEVELOPMENT IN THE 1980s: LESSONS LEARNED

SUMMARY

Five considerations motivated research on part-task training conducted by the Aircrew Training Research Division during the 1980s. First, the Air Force needed low-cost, but highly effective training devices. Second, unit-level training needs were not being addressed satisfactorily. Third, the rapid development of microcomputers offered new training development opportunities. Fourth, the cognitive information processing approach to human learning was gaining acceptance in the educational community. Finally, front-end analyses of potential device applications and cost-benefit studies indicated that research and development (R&D) of part-task trainers offered great rewards.

The program consisted of R&D activities on seven projects, or part-task training systems. The first, TACLAB, trained tactical pilots in planning strike missions. The Flight Decision-Making Assessment Task device trained and assessed flight-related cognitive skills. Following these projects in development, the Desk-Top Trainer for aircrew procedures instructed pilots in the programming of F-16 air-to-surface weapons modes. The fourth project, the Radar Warning Receiver Trainer, trained aircrew members in electronic warfare. The Fuel Savings Advisory System Trainer taught C-141 and C-5A pilots to operate an advanced autopilot avionics system. A special application of videodisc technology became a classroom teaching aid that supported low-altitude flight awareness training. The most recent project, the F-16 Air Intercept Trainer, trains pilots in a critical combat skill: air intercepts.

This report stresses that involvement with, and support from, the user was a key ingredient in the program's success and points out other "lessons learned." These include envisioning a desired end state, avoiding high-risk development efforts, building a small but dedicated and talented group to accomplish program objectives, and defending the effort in its early stages. The report concludes with a discussion of possible future directions for this program.

I. INTRODUCTION

Although many factors led to the Aircrew Training Research Division's part-task training development program, perhaps three were predominant. One was the realization that the large, expensive, full-mission, high-fidelity aircraft simulator would have difficulty surviving in an increasingly cost-conscious Air Force. A second was the awareness of unmet unit-level training needs (particularly the utilization and employment of aircraft systems and subsystems). A third was the emergence of new technological opportunities as a function of microprocessor development.

Certainly there were other considerations. In many cases, part-task training approaches better satisfied the training requirements of the Tactical Air Forces. Also, the cognitive science approach was beginning to influence training and education – specifically, instructional design issues. The results of a Risk and Cost Benefits Analysis performed on advanced concepts of part-task training were highly favorable. The following pages discuss how these elements coalesced to produce a vigorous and successful technology development program.

Air Force Requirement

George Washington is reported to have said, "To be prepared for war is one of the most effectual means of preserving peace." Satisfying this need for preparation, however, is not easily or cheaply done. Preparedness requires large expenditures of human and material resources.

Modern weapon systems possess awesome destructive powers but are worthless without the capability to employ them. This is why in the United States Air Force, as in all military organizations, training to acquire, maintain, and improve warfighting skills is a continuous undertaking. New threats emerge, and we must find new methods (i.e., equipment or techniques) to counter them. The result is additional training requirements. Frequently, these call for costly new training devices and generate a procurement process of long duration.

To minimize expense and maximize instructional benefit, the Air Force generally tries to determine how much training capability is sufficient. This attempt to avoid "gold-plating" aircrew training capabilities has led to consideration of training media covering the entire spectrum of cost and fidelity. At the high end are operational test ranges (200 to 300 million dollars); at the low end are chalkboards ($10 to $25). Between these extremes are training media such as the aircraft itself, weapon system trainers (WSTs), operational flight trainers (OFTs), part-task trainers (PTTs), computer-based instruction, and sound-slide presentations. The objective of the training manager is to derive the greatest value from the lowest-cost medium that will meet the training requirements before progressing to more expensive media.

Part-Task Training Rationale

Part-task trainers offer great cost advantages over higher-fidelity media such as simulators and aircraft. Equally important for their utilization in training programs is the rationale, derived from theoretical studies of learning, that strongly supports their use.

Skilled performance is developed by establishing conditions that require the learner to identify and combine the stimulus, cognitive, and response elements of a task into coordinated spatiotemporal patterns of receptor-effector activity as a function of appropriate feedback. Practice under appropriate conditions increases the possibility of a correct response, decreases reaction time, and optimizes accuracy. For training economy, suitable conditions for these processes can often be provided in part-task environments, precluding the requirement for the more expensive, higher-fidelity devices.

"Part-task training" is a term derived from a pedagogical technique ("divide and conquer") frequently used to facilitate the learning process. It is common knowledge that lengthy or complex material may be more quickly or easily mastered if it can be broken down into smaller parts (Orbison, 1944). As used herein, "part-task training" refers to a diverse set of procedures for sequencing training. These part-task training procedures have two basic requirements: (a) to specify a method for partitioning the task for training, and (b) to provide a method for reintegrating the task as training progresses. Procedures for partitioning and reintegrating a task depend on the task structure (e.g., the pattern of relations among task elements) and have a marked effect on the success of part-task training (Knerr et al., 1986, p.11).

Two conditions are essential for the part-task training approach to be successful. First, the material or task to be learned must be capable of being partitioned in a meaningful fashion. If the intrinsic organization of the material or task is such that it cannot be segmented, fractionated, or simplified into logical and integral units, part-task training is not practical. Second, the time or effort required to recombine the "parts" should, in the long run, show savings (in either time or resource expenditures) over the whole-task approach. Given that these two conditions exist, part-task training offers a number of advantages. Motivation increases because the learner experiences many small successes throughout the training session. Fatigue lessens because the training session may be distributed over time. Feedback, or knowledge of results, can be made more specific to the elements to be learned. Learners are not overloaded with information before they are able to assimilate it or place it in proper context. Thus, the "part" approach to training is often the method of choice.

Microprocessor Technology

The emergence and rapid development of the microcomputer was the major technological impetus for the Aircrew Training Research Division's part-task trainer program described in this report. Therefore, a brief history of microprocessor technology is presented here.

Many researchers agree that the Intel 4004 was the microprocessor's starting point. This 4-bit device was marketed in the early 1970s and was incorporated in hand-held calculators to upgrade their capabilities. By the mid-1970s, 8-bit machines based on the Intel 8008 microprocessor could honestly be considered to be "real" computers in their own right. The actual beginning of the personal computer (PC) occurred when "do-it-yourself" kits became available in 1975 from a small firm in Albuquerque (MIT) and the assembled Altair PC debuted about 1977. The advent of the Apple and Radio Shack PCs shortly thereafter started the PC boom. At the beginning of the 1980s, Intel's 80186 microprocessor increased the capacity of these devices to 16 bits. It was at that time that a similar machine, the Z80-based Cromemco, was used to drive an electronic combat part-task trainer designed and built by the Aircrew Training Research Division. By the middle of the 1980s, PCs using VME busses and the Motorola 68000 board were in production. Now "Crays on a chip" are available, and the microcomputer has matured to the point where it can replace the minicomputer for most applications.

The Division's scientific and engineering personnel realized that the microprocessor could provide the "heart" of part-task training devices at very low cost. The capabilities inherent in the PC could take computer-based training beyond the "page-turner" stage where it stagnated for so long. In a sense, the PC might do for aircrew training what the Model T had done for personal transportation. Like the Tin Lizzie, the PC was affordable and easily operated and maintained; and everyone could have one at home (i.e., in the squadron).

Risk and Cost Benefit Analysis

Upon reflection, the value of part-task training applications to aircrew training should have been obvious; but, in fact, it was not. The potential for the technology seemed likely, but few envisioned exactly how and where "micros" would fit into aircrew training. Some effort seemed warranted to substantiate opinion with more factual information. Accordingly, a Risk and Cost Benefit Analysis (RCBA) was accomplished in the fall of 1982. The work was performed by Dr Robert W. Stephenson at Air Force Human Resources Laboratory (AFHRL)[1] Headquarters. The resulting document (Stephenson, 1983), convincingly confirmed the faith of the believers in microcomputer-based, part-task training as a practical technology.

The purpose of that RCBA was to develop and report information relating to the costs, benefits, and risks involved in pursuing the part-task training research and development (R&D) program. The approach used in the analysis broke the program down into three phases: an R&D phase, an acquisition and deployment phase, and finally an operational evaluation phase. The analyst realized that these phases probably would not be sharply delimited. The phase framework, however, was a useful analytic tool for the RCBA study.

The Aircrew Training Research Division at Williams Air Force Base conducted the R&D phase on-site. Though this was viewed primarily as an "in-house" activity, there was frequent and intense communication with operational subject-matter experts. These personnel provided critical insights and suggestions that strongly influenced the design of the prototype part-task trainers. The assistance given by the operational community in this first phase was reciprocated in the acquisition and deployment phase, as AFHRL provided administrative and contractual expertise

[1]AFHRL has been redesignated Human Resources Directorate, Armstrong Laboratory.

to [illegible] We visualized the operational evaluation phase as [illegible] conducted jointly by AFHRL and operational command personnel.

The RCBA study identified four classes of benefits resulting from the part-task training program: training device procurement cost avoidance, reduced formal training costs, improved quality and efficiency of continuation training flying hours, and reduced accidents. The benefit estimates were restricted to Air Force applications even though it seemed likely that the Army and Navy would also gain from the work. The bottom line of the RCBA study was clear. The risks associated with the program were very low, with a probability of failure of 5% or less. The overall benefit-to-cost ratio was 15.3:1 meaning that for each dollar invested, the Air Force should [illegible]

Major Command (MAJCOM) Survey

During the early 1980s rapid growth in the acceptance and utility of microcomputers in business, industry, and government gave clear indications of the significance of this technology for training. From a laboratory perspective it was obvious that the potential of the microcomputer for aircrew training was already considerable and would become greater as a result of burgeoning research and development within the computer industry.

But the laboratory also needed an assessment of the value of this technology as perceived by potential users in the aircrew training community. Accordingly, we surveyed selected Air Force aircrew populations across a diversity of operational weapon systems to obtain their opinions about the application of this emerging technology to support their training requirements (Edwards, 1987). Results from these surveys identified classes of training tasks that could be supported by microcomputer-based technology.

We used task listings for aircrews in B-52, KC-135, C-130, C-141, and F-15 aircraft to construct questionnaires by which operators rated the utility of various types of training devices for training each task performed during their missions. Ratings data were tabulated and summarized for each crew position in the selected weapon systems to determine those tasks for which the microcomputer was judged to have utility as a training device. In general, tasks identified as being compatible or supportable with microcomputer technology tended to fall into three classes: (a) procedures related to aircraft subsystem operations and checklists, (b) monitoring and computational tasks associated with aircraft systems control, and (c) cognitive tasks such as decision-making associated with planning or carrying out missions.

Training fidelity requirements for these tasks seemed to be within the capabilities of the microcomputer. For example, we found requirements for essential task information, cues, practice, and feedback to be supportable. We could simulate many procedural tasks such as monitoring and manipulating aircraft subsystems by using computer graphics with touch-screen, mouse, or joystick inputs to reflect operator/control interaction. Cognitive tasks such as computations, problem solving, decision making and similar activities were found amenable to exploitation using this technology.

Results of the aircrew surveys confirmed the utility of microcomputer-based training devices as part-task trainers for a variety of aircrew training applications. These surveys provided a vital link in defining utilitarian matches between real-world training tasks and PC technology. The surveys also helped identify those technology gaps in specific training programs where low cost approaches could potentially improve training.

II. HISTORY OF DIVISION PROJECTS

The division's involvement in part-task training technology constituted an evolutionary activity. The R&D process followed a logical path, growing from simple to more complex devices, with predictable changes in capability and training intent. As microcomputer technology evolved, the training implications became more apparent to division psychologists and engineers. As our understanding of user needs deepened, the true potential of part-task training became apparent. The following sections describe how the division's learning curve and MAJCOM involvement progressed with each new system. The seven systems described below in chronological sequence of their development reflect the maturation of the technology and its systematic application.

TACLAB

Our first experimental application of a microcomputer as a training tool was the 1980 test of a concept called TACLAB, shown in Figure 1. In this instance, we used the microcomputer to improve the strike mission planning skills of tactical pilots.

Figure 1. TACLAB.

TACLAB software operated on a Radio Shack TRS-80 microcomputer interfaced with a digitized graphics tablet. A 35mm slide photograph projected the mission gaming area over the graphics tablet. The pilot could identify any point on the projected map using the digitizer as a computer input. Thus, the system provided a simple means of communicating selection of flight routes and other tactical decisions to the computer as part of the mission planning process.

The purpose of TACLAB research was to develop a way of assessing the skills associated with planning air strikes on unfamiliar targets in unfamiliar territory. The use of RED FLAG scenarios added realism and relevance to strike planning.

This research identified two particularly important mission planning skills: (a) the ability to acquire and retain information about unfamiliar operations areas; and (b) the ability to plan for detailed navigation, target attack tactics, and contingencies in unfamiliar environments. Because these are primarily tactical skills based upon pre-mission information, it was possible to measure the acquisition of these skills using methods which did not involve flight simulators or aircraft.

When the aircrew member entered his mission plan into the system, TACLAB was capable of automatically critiquing various aspects of the plan with comments and suggested alternatives. Pilots could use this information to improve tactics for actual or simulated missions.

TACLAB was a wholly experimental system and was never seriously proposed for operational use. However, TACLAB demonstrated the value of the microcomputer as an aid to aircrew training and research in three areas by

1. providing the opportunity to practice generating realistic attack plans using information on unfamiliar geographical areas;

2. automatically evaluating mission plans and tactics (decisions) proposed by pilots, thus providing a feedback source not available via conventional training activities; and

3. providing a support apparatus for basic research on the component processes of skill development associated with mission planning and tactics development.

Although the power and versatility of microcomputers have grown immensely since the development of TACLAB, assumptions derived from TACLAB concerning microcomputer training were validated in subsequent R&D. The proliferation of mission planning software by the computer industry during the 1980s is a good indicator of the relevance and success of the concepts pioneered by TACLAB. Thus, TACLAB represents a significant benchmark in laboratory research in defining the use of low-cost technology to improve aircrew training methods.

Flight Decision-Making Assessment Task (FDAT)

The Flight Decision-Making Assessment Task (FDAT), also started in 1980, was another early microcomputer application created by the Aircrew Training Research Division. In this case, the objective was to develop and validate a method for assessing flight-related cognitive skills. The research investigated the relationship of a pilot's flying experience to his vector/velocity aircraft control decision-making abilities. The FDAT training device is shown in Figure 2.

The FDAT was a vehicle control task programmed on a Terak 8510/A microcomputer. A representation of a flight corridor displayed on a computer/graphics screen simulated vehicle control. The task involved "steering" a simulated aircraft through the winding flight corridor in a series of moves. Moves made by numerical entry on the computer keyboard represented heading and velocity adjustments. The objective was to "fly" through the corridor with as few moves (control inputs) as possible. This required a continual assessment of speed and heading to anticipate subsequent maneuvering of the simulated aircraft through the course. Thus, the number of moves required to complete the task indicated efficiency of control decisions as a component of flight skill.

Samples of pilot populations representing a range of ability from novice to expert were tested using FDAT. Nonpilots also performed the task. Findings showed that scores on FDAT correlated highly with pilot experience and flying hours. Pilots with a greater amount of flying time scored higher (performed more efficiently) than those with less flying time. Undergraduate student pilots who graduated in the upper 10% of their classes scored higher on FDAT than did those of lower class standing. The performance of nonpilots on FDAT was substantially lower than that of any of the pilot groups.

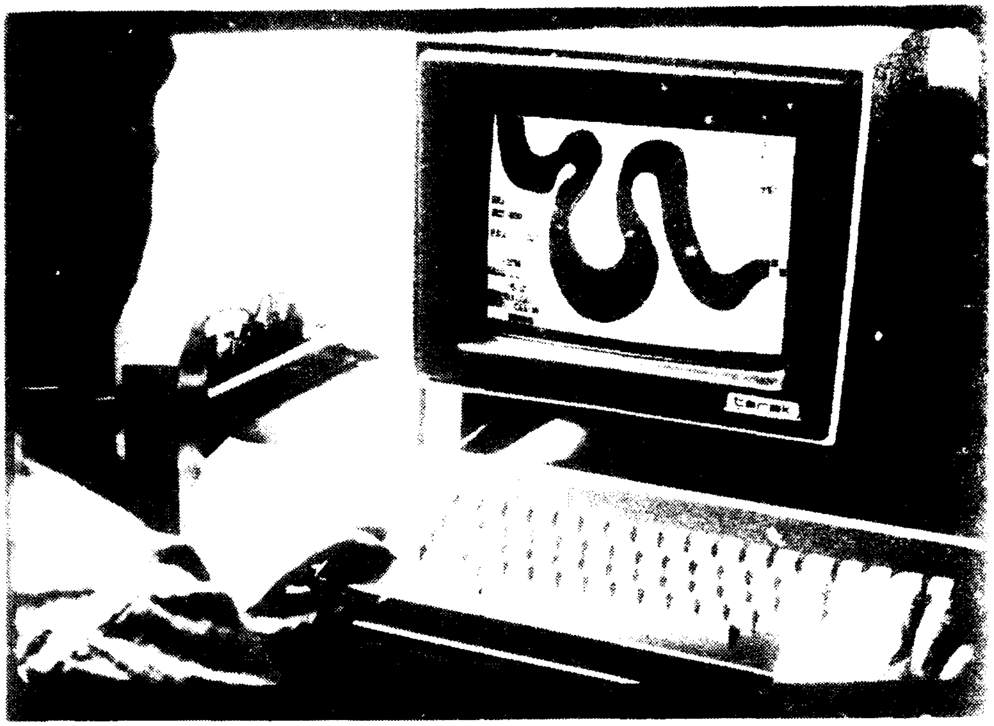

Figure 2. **Flight Decision-Making Assessment Task Training Device.**

FDAT made a significant contribution to laboratory research in part-task training because it proved that limited-fidelity flight simulations such as FDAT's abstract flight environment and dynamics, when correctly applied, are effective for assessing certain aircrew cognitive skills (DeMaio, 1983).

Desk-Top Trainer (DTT) for Aircrew Procedures

The DTT was actually the first microcomputer-based, part-task training device developed by the Aircrew Training Research Division. The DTT is depicted in Figure 3. The project began in mid-1981 and produced a device to train pilots in the programming of the air-to-surface weapon modes of the F-16 Stores Management System (SMS).

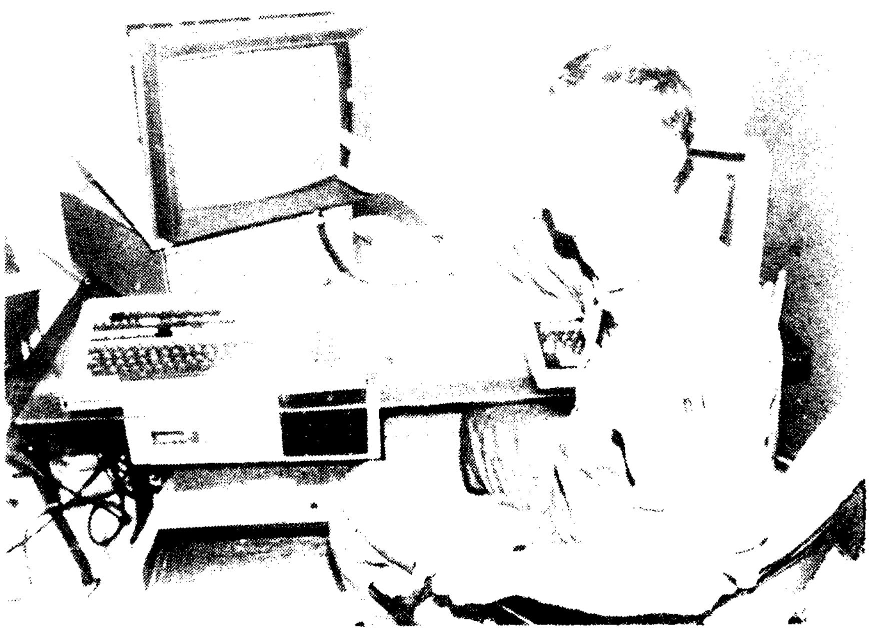

Figure 3. **Desk-Top Trainer.**

In the F-16, the SMS is a subcomponent of the Fire Control Computer (FCC). One of its functions is to preset various release parameters for various types of air-to-surface weapons. The SMS control panel in the cockpit is an alphanumeric display about 5 inches square surrounded by a series of pushbutton selector switches. By activating these switches in the proper sequence, the pilot can select, inventory, or modify delivery parameters for all on-board weapons.

A Chromatics II computer graphics system simulated the functions of the SMS. The system, programmed to display the SMS control panel, permitted the student pilot to actuate the various control buttons by pressing the graphics display screen. A touch-panel superimposed on the display sensed the pilot's selection and signaled the computer as to the selected control input. Instructional software was self-paced so that the student could learn the operation of the SMS without the aid of an instructor.

We performed an experiment to evaluate the training effectiveness of this DTT in which 20 instructor pilots assigned to undergraduate pilot training at Williams AFB participated as subjects. None had knowledge of the F-16 SMS, which was used as the procedures task to be learned. Subjects were randomly assigned to either an experimental or a control group.

Subjects assigned to the experimental group received the self-paced SMS training program via the DTT. Subjects assigned to the control group received the same instructional content and sequence as the computer program, but in the form of an illustrated programmed text.

To measure the effectiveness of the two types of training, subjects performed weapons selection and delivery parameter modifications on a real SMS panel installed in an F-16 simulator cockpit. Upon completion of the pre-training (either the DTT or the illustrated programmed text), subjects went directly to the simulator, where they performed several criterion tasks. Subjects received a general orientation to the F-16 simulator cockpit and the SMS control panel. An instructor told them to execute five tasks designated on each of five flash cards. Each of the tasks required the subject to perform weapons delivery parameter modifications using the SMS control panel. As instructed, subjects completed each task as quickly and accurately as possible, and proceeded to the next task. All subjects received the same ordering of tasks. For each subject, we recorded the time to complete each task, the number of errors made, and the total elapsed time for each subject.

Data analysis showed that the Desk-Top Trainer group performed the criterion tasks in significantly ($p < .01$) less time, and with significantly ($p < .001$) fewer errors than the text-trained group. The results demonstrated the potential of an inexpensive computer graphics system as a convenient, effective, and low-cost substitute for certain aspects of aircraft or simulator training, with concomitant training cost reduction (Pohlman & Edwards, 1983).

Radar Warning Receiver Trainer (RWRT)

Proficient operation of the radar warning receiver can mean the difference between life and death for tactical fighter pilots. During combat missions, the radar warning receiver provides critical information to the pilot about the presence and status of enemy threats including surface-to-air missiles, anti-aircraft weapons, and other aircraft. The pilot must be able to recognize and interpret threat information to avoid or defeat threats. These skills are difficult to acquire and maintain, and pilots have little opportunity to practice them in realistic situations.

The development and evaluation of the RWRT was a joint effort started in 1983, between the Aircrew Training Research Division and the Tactical Air Command (TAC) to determine the suitability of using microcomputer-based technology to provide TAC pilots with essential electronic combat skills. The device, shown in Figure 4, was designed around a Cromemco Z80-based microcomputer equipped with a color graphics system. Instructional software, programmed as a set of self-paced lessons, was menu driven so that the individual student pilot could receive training without the support of an instructor. Lesson content included threat signals (both visual and aural), radar warning system operations, radar scope/symbology interpretation, and malfunctions. In addition, the training package simulated real-time combat scenarios, which gave the student an opportunity to use the warning system as it might be used in actual combat. The 58th Tactical Training Squadron (TTS) installed the RWRT for academic training at Luke AFB, Arizona. Instructors and students in the B-course syllabus (replacement training unit) evaluated the training utility of the device.

Figure 4. **Radar Warning Receiver Trainer**.

Twelve instructors and six student pilots participated as subjects in the evaluation. Each received an explanation and demonstration of the device using unclassified information. After the demonstration, each participant took as much time as desired to practice with the device using the self-instructional mode of operation.

Following training, each participant completed a questionnaire. The questionnaire asked them to rate the usefulness of the device for various subcategories of radar system training such as symbology, control panel operation, azimuth operation, audio signal generation, system operation, and malfunctions. Participants used a 5-point rating scale ranging from "Not useful at all" to "Very useful" to assess the various aspects of the training device.

The overall evaluation of the RWRT showed that both instructors and students rated the device as "useful" to "very useful" across all aspects of the training and suggested that the trainer would be of greater value to students than to operational pilots. Evaluation data also showed the need for modification of several training features to improve ease of use. The data showed the RWRT offered flexible, yet inexpensive training for radar system skills and that pilot acceptance and assessment of utility were quite high.

The RWRT project was important for two reasons. For one, it was the first case in which the laboratory used microcomputer-based technology as an experimental testbed device for operational unit training. For another, it was the first time that the benefits of working with MAJCOM subject-matter experts in the design of a training device were fully realized (Brooks, 1985).

Fuel Savings Advisory System (FSAS) Trainer

The development and evaluation effort undertaken in 1984 on a training device for the Fuel Savings Advisory System on C-141 and C-5A aircraft was timely in that it afforded the opportunity to assess the training effectiveness of ... advice – an issue raised by the DTT research. This effort enabled us to make a direct comparison of training effectiveness between a computer-based device and actual aircraft equipment in an operational environment.

In the early 1980s, the Military Airlift Command (MAC) retrofitted C-141 and C-5A aircraft with a "super" autopilot called the Fuel Savings Advisory System (FSAS) to maximize aircraft fuel efficiency. Training of aircrews in the operation of the new system became uncertain due to a cut in funding from the procurement program for two part-task trainers. Thus, MAC faced the problem of finding some means to qualify aircrews on FSAS operation before attempting aircraft missions. The only apparent recourse would be to use the aircraft on the ground to provide the initial training

However, another training option was proposed: simulation of FSAS using microcomputer-based graphics and software. MAC instructors developed such a part-task trainer at HQ MAC/DOT and 63d Military Airlift Wing/DOT, with Aircrew Training Research Division personnel providing consulting assistance. Trainer software included G-TEACHER, an English language courseware authoring package. The trainer hardware consisted of a Northstar microcomputer equipped with a Micro Angelo graphics processor, color monitor, and touch-screen (see Figure 5).

Figure 5. **Fuel Savings Advisory System Trainer.**

At MAC's request, division personnel performed a training effectiveness evaluation of the FSAS trainer at Norton AFB, California. Twenty-six C-141 pilots served as subjects. All received general information about the FSAS via classroom lecture prior to actual hands-on training. We randomly assigned the subjects either to an experimental group ($n = 13$) to receive training on the part-task device, or to a control group ($n = 13$) to receive training on the flight deck of an FSAS-equipped C-141 while the aircraft was on the ground.

Experimental subjects used the Northstar-based FSAS trainer to learn the FSAS basic procedures. They followed the self-paced program and practiced in the trainer until they were confident that they could perform the tasks equally well in the aircraft. Upon completing the computer-based training, experimental subjects went to the aircraft, where they were tested for their ability to perform FSAS tasks. Subjects were tested and remediated until they were able to achieve criterion proficiency, a rating of 3, which indicated ability to complete all tasks correctly without assistance.

Control subjects received FSAS training in the aircraft. They received the same lesson content and sequence of tasks as the experimental group. The subjects were trained, remediated, and tested on each basic task or operation of FSAS until they reached a proficiency rating of 3 for all tasks.

Thus, all subjects were trained to a specified level of proficiency on all tasks. The data collection used standardized and controlled training procedures and content. Time to criterion proficiency provided the basis for comparing transfer-of-training effectiveness from the experimental trainer to the aircraft using a standard transfer effectiveness ratio (TER) for this assessment. Applying this formula to the mean training times from the experimental and control groups yielded a TER of 1.04. The obtained TER showed a somewhat better than one-to-one training ratio for the experimental device as compared to the aircraft equipment for FSAS training purposes. Stated another way, the microcomputer-based, preprogrammed training was slightly more effective than the actual aircraft equipment (with instructor) for training FSAS operation.

These findings permitted direct comparison of training costs between the experimental device and the aircraft. Systematic analysis of both training alternatives as applied to the training of all MAC C-141 and C-5A aircrews showed that a cost-avoidance of over $8 million could be achieved by using the FSAS part-task trainer instead of the aircraft to qualify MAC aircrews on basic FSAS procedures.

The importance of the research (Edwards, 1986) is that it provided a direct comparison of training effectiveness between the actual aircraft equipment and a very low-cost alternative training environment. Edwards used a classical transfer-of-training paradigm to reach the following conclusions:

1. Microcomputer-based graphics simulations can be effective for training many aspects of aircrew procedural tasks.

2. Correctly applied, such technology has large-scale cost-avoidance potential for training aircrews to perform basic avionics subsystems operations.

Low-Altitude Flight Awareness (LAFA) Videodisc

In point of fact, the LAFA Videodisc (shown in Figure 6) was a classroom teaching aid rather than a stand-alone, part-task trainer. The objective of this 1985 effort was to investigate the utility of videodisc-mediated instruction to support low-altitude flight awareness training.

Figure 6. **Low-Altitude Flight Awareness Videodisc.**

Low-altitude flight permits the tactical pilot to evade radar detection by flying at high speeds near the ground. Low-altitude flight is difficult and dangerous because the pilot must perform a variety of mission-related tasks while maneuvering at minimum altitudes. Although terrain clearance is the highest priority, other tasks are performed simultaneously including navigation, threat avoidance, weapons delivery, and communications. The time-sharing aspects of these tasks require learning specialized skills to negotiate successfully a hazardous flight environment. The pilot must learn to "read" terrain features of many varieties. Thus, systematic training in awareness of the visual dimensions of low altitude flight is essential.

The 162d Tactical Fighter Group, Air National Guard, Tucson, Arizona specialized in low-altitude flight training as part of the attack mission of the A-7D aircraft. This group produced a Low-Altitude Training Course, which had a unique training doctrine, an extensive and refined training manual, a syllabus, and other training materials. Pilots from units throughout the country attended the course, which was conducted four to six times per year.

Analysis indicated that student performance on the academics portion of the course would improve significantly if students were pre-trained in low-altitude visual perception as a means of increasing cue recognition. Such training could enhance understanding of terrain characteristics, visual phenomena, and associated visual cue discriminations. Because of the complex character of the visual environment, the training needed an extensive variety of visual examples. An efficient means of manipulating a library of visual materials to support instruction was also necessary. To satisfy these requirements, the researchers selected a microprocessor-driven videodisc.

For this research application, the videodisc was a menu-driven picture file. While lecturing, instructors could access any material from the disc by using a hand-held controller. For example, if instructors wished to show examples of terrain where there are few visual references as altitude cues, they could call up a variety of such examples (snow, water, sparse vegetation, etc.). They could also freeze the image, back up, and replay to make a point visually. Most of the examples in the videodisc were dynamic footage taken from moving aircraft. A few of the examples were still pictures with graphic enhancements or special effects.

The students cannot obtain in any other way the visual concepts taught in the Low Altitude Training Course via the videodisc. Neither a "high-end" simulator nor the aircraft itself can provide this training because the student pilot must first learn *what* to look for, and must accomplish this prior to flying the aircraft. The structure of information and the concepts gained through this course are critical to flight safety in the low-altitude regime. As a consequence, the videodisc continues to be essential to the Low-Altitude Course. It alone accounts for 25% of the course content and permits a unique method of teaching visual concepts critical to safety of flight.

The Air Force National Guard has used the LAFA Videodisc continuously since 1986. User acceptance has been extremely enthusiastic and the device is a vital feature of their low altitude training program.

F-16 Air Intercept Trainer (AIT)

A project begun in 1986 has grown into a joint venture among the Aircrew Training Research Division, the Air Force Reserve, the Tactical Air Command, and the Air National Guard. At the core of this project is the F-16 Air Intercept Trainer (AIT), a part-task training device that serves a dual function. It is both a research vehicle for investigating skill development and retention and an operational training device for the Tactical Air Forces. The AIT is being used to demonstrate how improved training methods and technology can be rapidly transitioned to the user. Figure 7 shows the AIT.

Figure 7. **F-16 Air Intercept Trainer.**

The AIT focuses the pilot on a single, critical combat task, the air intercept. The AIT can support training at an individual level, or networked AITs can support team training. For the individual pilot, the AIT trains basic intercept skills such as radar use, intercept geometry, aircraft management, and situational awareness. Several AITs networked together permit pilots to develop multiship tactics against maneuvering targets in the database, or to fly against each other in combat scenarios.

The AIT simulates the essential cockpit controls and displays which are active during execution of the beyond-visual-range aspects of air-to-air intercepts, including the head-up display (HUD) and the radar electro-optical (REO) display. Ownship maneuver capabilities are provided using F-16 throttle and stick controls. Flight dynamics in the trainer accurately simulate relative target movement for single and multiple targets. Aircraft system simulation and flight dynamics are managed by the 68020 microprocessor of a Motorola VME 2000 system programmed in Fortran.

The AIT incorporates a student/instructor control station from which either the instructor or the student can select and manipulate instructional menus and training scenarios. Instructional features include the capability to freeze/resume simulated aircraft flight at any time, and to display plan and overhead objective views of the ownship and adversary aircraft within the target area.

In accord with the dual function of research and training, the AIT product improvement program has both instructional and engineering components. The instructional aspects include (a) assessing student skill acquisition, (b) determining the level to which skill automaticity can be acquired, (c) investigating skills maintenance requirements, and, (d) alleviating instructor workload through the development of programmed instruction. The engineering issues include: (a) defining the capabilities of state-of-the-art microcomputers for aircrew training, including reliability and maintainability; (b) applying technology to increase training capability and reduce costs; (c) designing for hardware/software modularity and transportability between the full-mission simulator and the part-task trainer; and (d) maintaining concurrency with aircraft and radar.

To determine the training effectiveness of the AIT, we conducted a formal, controlled experiment at Luke AFB. B-course student pilots, who had no prior knowledge of air intercepts, were randomly assigned to either an experimental group or to a control group. After classroom training on air intercepts, experimental subjects ($n = 25$) learned to perform basic skill components of air intercepts in the AIT, followed by practice of air intercepts in an operational flight trainer (OFT) which simulates the F-16C aircraft. Control group subjects ($n = 25$) received only the standard academic training on air intercepts prior to OFT training. All subjects received identical practice in the OFT on three basic types of intercepts defined by adversary aircraft position relative to the ownship at initial point: (a) head-on, (b) 135-degree front quarter, and (c) beam (90 degrees). We statistically analyzed differences between experimental and control group means on performance components and final performance criterion levels achieved. The results show that the mean proficiency ratings of AIT-trained subjects were higher than those of non-AIT subjects on all intercept component skills across the three types of basic intercepts. These differences were statistically significant at the following levels: radar use ($p = .068$); aircraft control ($p = .016$); intercept geometry ($p = .004$); situational awareness ($p = .01$); overall intercept ($p = .009$). Also, criteria proficiency was obtained by the AIT-trained students on more types of intercepts than by the nonAIT-trained students (2.7 vs 1.5). This difference was significant at the .035 level.

These findings by Edwards and Hubbard (1990) provide substantial evidence that AIT training increases the level of skill attainment in the OFT. Thus, the AIT has the potential to significantly reduce training time for air intercepts in the simulator compared to standard syllabus procedures.

III. PROGRAMMATICS

The nuts and bolts of administrative processes are not exciting, but they are a necessary part of a successful Air Force program. The part-task training program was no exception to this generalization. The program was able to achieve its goals because it established a proper "bureaucratic" foundation and was able to use this to advantage. For purposes of discussion, the programmatics are subsumed under two headings: requirements and technology transfer.

Generation of Requirements

The division conducted the program under the aegis of two Requests for Personnel Research (RPRs) and two Memorandums of Agreement (MOAs). RPR 82-06, Development of Low-Level Awareness Training, was a joint RPR with both the Strategic Air Command (SAC) and TAC as customers. RPR 84-10, Development and Evaluation of a Part-Task Trainer for Aircrew Electronic Combat Training, had the Tactical Air Warfare Center (TAWC) of TAC as its primary user, with MAC as a secondary beneficiary. Two MOAs supplemented these RPRs. One of these, with MAC, focused on the application of part-task training methodologies to electronic combat training. The goal was to develop a part-task training environment that would train aircrews to recognize and consider critical situational factors in making tactical decisions in a variety of threat situations. In order to accomplish this, we modified the Radar Warning Receiver Trainer for special operations training. This required interaction between HQ MAC/DOT, 1st Special Operations Wing (SOW) (Hurlburt Field, Florida), and the division, to conduct a task analysis, identify system simulation requirements, select problem situations, develop software, and structure feedback. Following the completion of these activities, the division turned over responsibility for maintenance and support of the part-task training device to MAC. We provided the required documentation (e.g., system specifications, user guides, software documentation, technical manuals) with the device to enable its continued operation.

The other MOA was with TAC. This agreement defined the responsibilities and activities required for the planning, design, development, implementation, and evaluation of an experimental part-task trainer (i.e., the F-16 AIT) for TAC. Aircrew Training Research Division personnel developed the device to support training of F-16C/D pilots at the 58th Tactical Training Wing (TTW), Luke AFB, Arizona. The basic trade-off involved in this agreement was that the Division would fund the development and evaluation of the training device and turn it over to TAC following completion of the R&D effort. TAC supported field research on part-task training to include providing facilities and experimental subjects. Thus, the experimental device ultimately served a training need identified by HQ TAC/DOT and, in the interim, supported behavioral research conducted by Armstrong Laboratory.

Technology Transfer

In accordance with command directives and to ensure the expeditious transfer of the program's methodology and technology, a Technology Transition Plan (TTP) was developed. The TTP framework provided two benefits. First, the user gained from the rapid development and transition of technology because of the direct relationship between the laboratory effort and the field environment. This guaranteed that the product would be optimally responsive to operational training unit requirements and that it would be compatible with the unit's training philosophy and management process. Second, the Division had the opportunity to develop and test new concepts in the user environment, to perform empirical research in a real-world setting, and thereby to obtain generalizable data.

The actual transition strategy employed consisted of giving the hardware specifications, parts lists, software documentation, etc. via an MOA to a training systems agency (e.g., TAC 444th Training System Center (TSC)). This agency is now building the production version of the part-task training devices and provides the necessary logistical support (i.e., maintenance and spare parts). Meanwhile, as the Laboratory develops software enhancements such as performance measurement and instructional aids, these are transferred directly to the users.

IV. PART-TASK TRAINING PROGRAM LESSONS LEARNED

Many view the Part-Task Training Program as one of the outstanding efforts in the Aircrew Training Research Division's research and development arena. As the program history shows, part-task training devices have been enthusiastically accepted by Air Force MAJCOMs, have shown positive training transfer, and have reduced training costs. The purpose of this section is to explain the steps that were taken to reach this successful conclusion and present them as examples which, if followed, might assist other programs to achieve their goals. The steps are presented as six key points, or critical factors, that were the essential elements in shaping the outcome of the Part-Task Training Program.

Envisioning Success

To begin with, the program must have some "vision" of an ideal state that will be a natural and automatic result of program activities. The theoretical and practical issues associated with part-task training contributed to a well-defined philosophy that provided a strong framework around which we structured the program. The vision of what a part-task trainer should be and how it should be employed gave the program a necessary coherence and purpose. We saw the ultimate part-task trainer as a stand-alone device with built-in performance measurement capabilities and the ability to assist and manage instruction. It would be highly reliable and able to operate in a typical Air Force classroom or office environment. The consequences of these objectives were highly conducive to program success. First, the user gained a turnkey operation that freed the instructor from mundane teaching (or even completely removed personnel from the task). Second, such a device provided an excellent tool for research. The main point, however, is that a well-established concept of design and utilization underlaid the effort.

Avoiding High Risk Development

The second lesson we learned from the Part-Task Training Program is to employ a technology (and/or methodology) that is either relatively mature *or* being rapidly developed by other agencies. Such a strategy reduces risks and costs. In the case of the program under discussion, part-task training was an established instructional process. Equally important was the mushrooming of microprocessor technology. The technology was "paid for" by industry, but our division was fortunate to have several individuals who were alert to the potential it represented. On the engineering development side, we viewed the microprocessor as a means for reducing the bank of minicomputers required to drive the Advanced Simulator for Pilot Training. On the behavioral research side, we saw the microprocessor as the engine that could transport computer-based instruction and computer-managed instruction from dreams to training reality. Of course, even if the opportunity is ripe for exploitation, there must still be the will to take advantage of it. The technology/methodology must be mastered for the specific application desired. It requires intense homework and trial-and-error experimentation.

Cultivate the Customer

The third point follows as the obverse of the second. The product (as described in the paragraph above) is only one side of the coin. The other is the customer, or user. In the Part-Task Training Program, the survey (Edwards, 1987) conducted early in the life of the project located the "right" Air Force customers and defined the major areas where part-task devices would help solve their training problems. There are three other considerations to keep in mind at this point. First, it is highly beneficial to program viability that the training problems have Air Force visibility. Second, the customer must have enough "clout" to provide credible support for the research and development effort. Third, as it was for many of the products of the Part-Task Training Program, the customer may be able to provide (or aid in obtaining) funding. As a rule, Air Force general officers pay close attention when pilots are willing to ante up their operations and maintenance dollars for a laboratory product.

Prove Program Value

The next step is to establish a credible benefits story. No matter how real and urgent the training problem, regardless of the technical excellence of the product and despite the customer's clamor, "beans" must be counted. The front-end analysis conducted early in the program was most useful in defending the resources necessary to accomplish the work. It is extremely important to prove the program's value with quantitative estimates of savings or cost-avoidance.

Nurture Genius

Turning to practical considerations (i.e., how to actually execute the planned effort), two actions enabled and sustained the program. These were growing a "skunk works" and protecting a "tender shoot." A small but dedicated and talented group performed the part-task training R&D work. This group was encouraged to take "ownership" of the program and run it with a product (not process) orientation. The immediate manager provided resources but very little direction and oversight. We believed that involvement and creativity are spontaneous events that flourish best when there is freedom and responsibility for individual actions. In the case of the Part-Task Training Program, this opinion proved to be fully justified. It is doubtful if the results achieved could have been produced with a more traditional managerial style.

Defend the Effort

With regard to the second action mentioned above, novel ideas or ways of doing business typically need to be "protected" from higher headquarters demands. From the outset, we made and kept a commitment to the Part-Task Training Program. In fact, it is interesting to note that many of the management approaches recommended by the new wave of consultants are consistent with this philosophy (e.g., Deming, 1986; Peters & Waterman, 1988). During the period when the Part-Task Training Program was beginning, many people frequently criticized and questioned it. By resolutely defending this program, the Division enabled it to mature in to a successful effort.

Summary

The foregoing discussion may be summarized in a few words. A program requires sufficient insight into real world problems to create a vision of a more desirable state. Vision alone, however, will not sustain a program. Effort must be applied to perfect the appropriate technology and methodologies, and the organization must establish customer rapport and document believable cost benefits. To fully realize the potential for a valuable and effective program, however, requires the addition of two more ingredients. An elite group of limited membership must be formed to work the problem areas, and immediate management must be steadfast in its support.

V. FUTURE DIRECTIONS

The division sees two major areas of activity, highly complementary of one another, as the future direction of the Part-Task Training Program. The first of these is applied research in learning and instruction – the primary thrust being the application of principles from cognitive science to Air Force training problems using part-task devices as the instrumental media for research and experiments. The second area deals with the development of training equipment the Air Force will employ at the unit level. The inexpensive and reliable microprocessor-driven, part-task trainer ideally suits and satisfies small unit training requirements. We will discuss these two related lines of effort in detail in the following sections.

Learning Research

The dominant principle behind most Air Force aircrew training is a stimulus-response behaviorism that has its roots in Skinnerian conditioning. This traditional conception of learning is being replaced in current educational circles by a more dynamic view of the learning process, "cognitive information processing." This newer approach to human learning, which falls under the general rubric of "cognitive science," is based upon the assumption that the brain-mind system is essentially structured like a programmable computer. We propose that such an approach form the central theme of all research involving the use of part-task trainers.

One of the division's former scientists, Dr Thomas H. Killion, suggested that cognitive science offers a variety of concepts which could guide and enhance the effectiveness of PTT applications. The research he proposed would determine the applicability of these concepts in the domain of aircrew training and evaluate the training enhancements which could be attained by using this approach. Four specific issues are of interest in this context.

One is the organization of declarative knowledge. The focus here is facilitating the learning and retrieval of a large body of related facts. Research on schema theory and on fact retrieval per se suggests that there may be optimal ways of structuring such an internal database to enhance its acquisition and retention.

A second issue concerns the development of automaticity in component skills. A variety of studies, primarily in the area of perceptual learning, have demonstrated the development of "automatic" processing in cases where consistent relationships can be established between specific stimuli and their associated responses. The development of automaticity is beneficial in terms of making critical stimuli more alerting and of enhancing the ability to process multiple stimuli in parallel (i.e., without a penalty in speed or accuracy). Some suggest that automatization of component skills allows the individual to allocate greater attention to higher-level processes such as comprehension or decision-making, thereby enhancing performance at these levels.

A third issue concerns the development of "mental models" of how systems/processes operate. These mental models allow the one to project the consequences of various actions and to determine appropriate responses to particular situations. Recent research suggests that the format in which we display a problem during training can affect the accuracy or effectiveness of the mental model that is developed.

A final issue relates to the development of expertise in solving complex problems in ill-structured domains. Substantial research on expert versus novice performance reveals differences in problem representation and in the richness of memory for relevant patterns, both of which affect problem solution. One of the key training issues is whether exposure to a structured sequence of representative problems can contribute to the development of expertise and support transfer to related problems.

Unit-Level Training

Unit-level training (ULT) promises to be a fertile field for part-task trainer R&D. The ULT arena was, of course, seen as the target of opportunity at the program's outset. At present, there are three major streams of development in which part-task trainers will be particularly useful in answering ULT needs: networked multiship exercises, systems automaticity training, and device instructional features enhancement.

The capability for networked multiship exercises would allow force-on-force training at the unit level. With the exception of RED FLAG exercises, the typical TAC fighter pilot does not receive extensive training in large-scale engagements. Upgraded versions of the Air Intercept

Trainer could be "tied" into other simulators (Air Force, Navy, Army) across wide geographical areas. This would permit many-versus-many dissimilar aircraft training as well as combined forces training. It is believed that the chance to practice participating in large-scale engagements offers enormous benefits for improving the warfighting skills of fighter pilots. Part-task trainers are a medium by which pilots can acquire this expertise.

As the section on learning research points out, achieving skill automaticity is a greatly desired state. In today's Air Force, opportunities to attain complete mastery of the skills needed to manage aircraft subsystems are sharply limited. Perhaps the most critical of these subsystem management skills are electronic combat, sensor interpretation, and weapons selection and delivery. Electronic combat skills are essential to survival in a sophisticated air warfare environment, but the training facilities (aircraft, instrumented ranges, etc.) are scarce. As a result, too few aircrews become proficient in their skills. Advanced radar, infrared, and electro-optical systems are standard equipment on all of the newer airplanes. Again, however, the capability of the Air Force to train crewmembers in their use is far below the desired level. The selection, arming, and release of missiles and bombs constitute a complicated procedure. If we could train these tasks to automaticity, the odds of successfully performing the mission would increase. These three examples represent but a small portion of the domain where part-task training devices and methodology would have a large payoff for the Air Force.

Along with the need for, and uses of, part-task training applications, the capabilities of the devices themselves should be enhanced. The basic requirement is to incorporate artificial intelligence capacities in the software. Once this is done, the part-task device transcends being merely a specialized medium for training. By developing computer-assisted and computer-managed instruction programs, a small but powerful *mini-training system* can be realized. Such a system can not only "teach" but also serve as a management information system to control training. When a performance measurement system is added, a self-contained schoolhouse is available to every Air Force squadron. Such a future is possible, and every effort should be made to ensure it becomes an actuality.

Although the end-state foreseen in the above paragraph is viewed as a desirable outcome, a final cautionary point must be made. This report's description of part-task training and part-task training devices, if not a paean to their utility, has certainly been highly favorable to both. But, as mentioned in the first section, part-task trainers are only the middle links in a chain of training media that stretches from cheap and simple to expensive and complex. The part-task method itself requires a final integrating step to weld individually learned units together before training may be considered complete. The attractiveness of part-task methods and devices should not lure the instructional designer into believing that a "philosopher's stone" of training, which transforms all problems into small, manageable pieces, has been found. A training system must always be viewed as a totality wherein a part is not disproportionately emphasized. If the part-task approach is permitted to dominate the instructional framework, it is possible that a suboptimal system will result. The designer cannot allow the training system architecture to become distorted through too much reliance on part-task methods and media. These are but as necessary and useful building blocks in a much larger training system structure.

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